

# Thermotolerance Acquisition in Broiler Chickens by Temperature Conditioning Early in Life—The Effect of Timing and Ambient Temperature<sup>1</sup>

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**ABSTRACT** Thermal conditioning of chicks results in improvements in performance and thermotolerance at marketing age. Conditioning has been found to be a sensitive process, dependent on age and the temperature used. The objective of this study was to assess the optimal timing and temperature for the conditioning processes. Six separate trials were conducted on male broiler chickens: the first two aimed to find the optimal age for thermal conditioning (1 to 5 d of age); the other four evaluated the optimal thermal conditioning temperature between 36 and 40.5 C. At 42 d of age chickens were thermally challenged to evaluate their ability to cope with acute heat stress. The highest body weight was achieved when

thermal conditioning had been applied at the age of 3 d, and it coincided with low feed intake and higher to significantly higher feed efficiency. These treated chickens showed relatively lower mortality rate under thermal challenge and lower to significantly lower Triiodothyronine (T<sub>3</sub>) concentration in Trial 2. Chicks that had been thermally conditioned at ambient temperatures (T<sub>a</sub>) of 36 and 37.5 C at the age of 3 d demonstrated the best performance characteristics and the ability to reduce T<sub>3</sub> concentration to the lowest levels during thermal challenge. It can be suggested, therefore, that a T<sub>a</sub> between 36.0 and 37.5 C, applied at 3 d of age is optimum for thermal conditioning of broiler chickens.

(Key words: thermal conditioning, broiler, thermal challenge, performance, thermotolerance)

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## INTRODUCTION

Chickens can be physiologically manipulated to better tolerate heat stress by acclimation to high environmental temperatures (Hurwitz et al., 1980; Yahav et al., 1995) or by thermal conditioning (Arjona et al., 1988, 1990; Yahav and Hurwitz, 1996; Yahav et al., 1997). One of the main disadvantages of acclimation to high ambient temperatures is the significant reduction in body weight, which results from the increased energy demands imposed by thermoregulation and the decline in feed intake. The main idea in the thermal conditioning process is to incorporate threshold changes that enable chickens to cope, within certain limits, with acute exposure to unexpected heat spells.

Short-term exposure of chicks to mild heat stress during the first week posthatch (36 ± 1 C; 70 to 80% RH; for 24 h at 5 d of age) resulted in growth retardation followed by an immediate compensatory growth phase. The result was a complete compensation for the loss of weight gain,

and higher body weight of the conditioned chickens at 42 d (Yahav and Hurwitz, 1996; Yahav et al., 1997a; Yahav and Plavnik, 1999). The higher body weight coincided with greater feed intake.

An acute exposure to extreme temperatures demands rapid and extensive responses by the chicken, mainly in the circulatory system. The regulatory hemodynamic changes observed in chickens acclimated to constant temperatures or to rapid temperature changes, such as those occurring during diurnal cycles, have not been observed in birds that have undergone acute exposure to high temperatures (Yahav et al., 1997a).

One of the mechanisms that induces thermotolerance involves the modulation of heat production through changes in circulating triiodothyronine (T<sub>3</sub>). The ability to reduce plasma T<sub>3</sub> concentration, especially during a thermal challenge, suggests an improvement in thermotolerance (Yahav, 2000).

Thermal conditioning is a unique phenomenon that elicits two mutually contradictory effects (Emmans and Kyriazakis, 2000): increased growth rate and increased thermotolerance. Therefore, fine tuning is essential to achieve positive responses in growth and thermotoler-

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**Abbreviation Key:** T<sub>a</sub> = ambient temperature; T<sub>b</sub> = body temperature; T<sub>3</sub> = triiodothyronine.

ance. The objective of the present study was to assess the optimal timing and temperature for the thermal conditioning processes.

## MATERIALS AND METHODS

### *Birds and Management*

Six sets of separate trials were conducted. The first was designed to determine the optimal age for thermal conditioning (Trials 1 and 2); the second to evaluate the optimal thermal conditioning temperature (Trials 3 to 6). Male broiler chickens (Cobb) were obtained from a commercial hatchery. At 1 d of age (Trial 2 and Trials 3 through 6), or on delivery (Trial 1), birds of extreme weights were discarded, leaving 240 of 280 (Trials 1 and 2) to be distributed among 24 groups (4 treatments  $\times$  6 replicates  $\times$  10 chicks) or 120 of 150 (Trials 3 through 6) to be distributed among 12 groups (2 treatments  $\times$  6 replicates of 10 chicks). The chicks were raised in battery brooders (under regulatory conditions) situated in a temperature-controlled room at 26 C. At 4 wk of age the chickens were transferred to temperature-controlled rooms (ambient temperature;  $T_a = 22 \pm 1$  C) and housed in cages. Water and feed were provided *ad libitum*. Feed in mash form was formulated according to the specifications of the National Research Council (1994). Trials 1 and 2 included chicks that were exposed to the same environmental conditions (36 C, 70 to 80% RH for 24 h) at different ages (1 to 3 d in Trial 1; 3 to 5 d in Trial 2). Each trial included four treatments: 1) an unexposed control group, 2) chicks exposed to the environmental conditions at the age of 1 or 3 d (Trials 1 and 2, respectively), 3) the same as Treatment 2 but at the ages of 2 and 4 d (Trials 1 and 2, respectively), and 4) the same as Treatment 2 but at the ages of 3 and 5 d, respectively. Trials 3 through 6 were designed on the basis of the results of the first two trials and focused on the optimal  $T_a$  for thermal conditioning. It included four trials, each with two treatments: an unexposed control group and a thermally conditioned group. In all trials, thermal conditioning for 24 h at RH of 70 to 80% was applied at 3 d of age. The following thermal conditioning temperatures were used: Trial 3, 36.0 C; Trial 4, 37.5 C; Trial 5, 39.0 C; and Trial 6, 40.5 C. At 42 d of age chickens from both experiments were thermally challenged by exposing them to  $35 \pm 1$  C and RH of 20 to 30% for 6 h.

At weekly intervals, body weight and feed intake were determined on an individual and a group basis, respectively. Body temperature was measured before and at the end of the thermal challenge period. Blood samples from the brachial veins of 10 birds were collected into heparinized syringes before and at the end of the challenge. The

blood was centrifuged at 3,000 rpm for 10 min, and the plasma was stored at  $-20$  C for further analysis.

### *Temperature Measurements*

Body temperature ( $\pm 0.1$  C) was recorded with a thermometer,<sup>3</sup> which was inserted 3 cm into the colon.

### *Blood Analysis*

Radioimmunoassay (RIA) for  $T_3$  was performed on plasma samples, with Pharmatrade-Veterinary applications of DPC Kits,<sup>4</sup> Kit No. TKC 35, characterized by intra-assay variation (cv) of 5.0 to 5.9%. The DPC kit had previously been validated for chickens by means of the RIA technique of Bar and Hurwitz (1979).

### *Statistical Analysis*

All results were subjected to standard statistical one-way ANOVA according to Snedecor and Cochran (1968), and Duncan's multiple-range tests (Duncan, 1955) were applied. The mortality rate was analyzed by chi-squared test. Means were considered significantly different at  $P < 0.05$ .

## RESULTS

### *Performance*

The optimal day for thermal conditioning at an early age (1 to 5 d) was assessed in Trials 1 and 2 (Table 1). Body weights in both trials were highest when chicks were thermally conditioned at the age of 3 d. These chicks also had lower feed intakes that resulted in significantly improved feed efficiencies. In Trial 1, the percentage of mortality during 6 h of thermal challenge at 42 d of age was 24.6, 26.2, 13.2, or 14.8%, respectively, for control chickens and for those that had been thermally conditioned on Days 1, 2, or 3. In Trial 2, the corresponding percentage of mortality was 26.6, 18.3, 25.0, or 15.5%, respectively, for control chickens and for those that had been thermally conditioned on Days 3, 4, or 5. The mortality rates were significantly lower in chickens thermally conditioned on Days 2 and 3, or 3 and 5 than for control chickens and for those conditioned on Day 1 or 4 (Trial 1 or 2, respectively).

On the basis of the above results, different  $T_a$  values were examined in Trials 3 through 6, to determine the optimal conditioning  $T_a$ . In Trials 3 and 4, in which the  $T_a$  during thermal conditioning was 36.0 and 37.5 C, respectively, body weights at 42 d of age were significantly higher than those of the controls (Table 2); these conditions also resulted in higher feed intake with improved (but not significant) feed efficiency. Thermal conditioning at 39.0 and 40.5 C resulted in negligibly higher weight gain compared with that achieved in the control birds. The mortality percentages during 6 h of thermal challenge at 42 d of age were 17.1 and 27.8% (Trial 3), 12.2 and 26.4

<sup>3</sup>Sika TT-7170, Dr. Sieber and Kuhn GmbH and Co. KG., P.O. Box 1113-34254, Kaufungen, Germany.

<sup>4</sup>Coat-A-Count, Canine,  $T_4$  and  $T_3$  kits, (Diagnostic Products Corporation (DPC), Los Angeles, CA 90045-5597.

**TABLE 1. The effect of thermal conditioning (TC) on broiler chickens at the ages of 1 to 3 and 3 to 5 d on body weight, feed intake, and feed efficiency (Trials 1 and 2, respectively)**

Treatment	Body weight <sup>1</sup> (g) (42 d)	Weight gain <sup>2</sup> (g/period) <sup>3</sup>	Feed intake <sup>2</sup> (g/period) <sup>3</sup>	Feed efficiency <sup>2</sup> (g/g)
<b>Trial 1</b>				
Control	2,136	2,081	3,976	0.524 <sup>ab</sup>
TC - Day 1	2,185	2,130	4,132	0.516 <sup>b</sup>
TC - Day 2	2,209	2,154	4,082	0.528 <sup>ab</sup>
TC - Day 3	2,209	2,155	3,962	0.545 <sup>a</sup>
SEM	38.83	38.79	79.27	0.009
<b>Trial 2</b>				
Control	2,034	1,983	3,441	0.576 <sup>ab</sup>
TC - Day 3	2,111	2,061	3,516	0.586 <sup>a</sup>
TC - Day 4	2,099	2,050	3,608	0.568 <sup>b</sup>
TC - Day 5	2,110	2,060	3,584	0.574 <sup>ab</sup>
SEM	29.50	29.78	53.45	0.006

<sup>a,b</sup>Within columns, in each trial, values with different superscript letters differ significantly ( $P < 0.05$ ).

<sup>1</sup>n = 60.

<sup>2</sup>n = six replicates of 10 birds each.

<sup>3</sup>Period from 1 to 42 d of age.

(Trial 4), 28.3 and 32.9% (Trial 5), and 23.5 and 34.2% (Trial 6) for treated and control chickens, respectively. In all trials, except Trial 5, the mortality percentage was significantly lower in the thermally conditioned chickens.

### Thermotolerance

Thermal challenge caused severe hyperthermia in broilers in all trials (Tables 3 and 4). However, body temperature ( $T_b$ ) of the thermally conditioned chickens was lower than that of the control, with the exception of chickens treated at 1 d of age (Trial 1). Plasma  $T_3$  concentration declined significantly in all chickens during the period of thermal challenge and was always lower in the thermally conditioned chickens. Of the chickens exposed to thermal conditioning on various days, those treated at 3 d of age had significantly lower plasma  $T_3$  concentrations than

those of control and Day-4-treated chickens (Trial 2, Table 3).

### DISCUSSION

Thermal conditioning is a unique management tool that enables the fast-growing broiler to cope with acute changes in environmental conditions (Yahav, 2000). It reconciles two conflicting requirements: growth and thermotolerance. Broiler chickens lose their ability to thermoregulate efficiently under extreme conditions because of their dramatically increased growth rate (Emmans and Kyriazakis, 2000). It must be noted, however, that acclimation (a procedure that affects body core temperature, the threshold core temperature for evaporative heat loss, sensible heat loss, body fluid distribution) integrates the physiological processes to improve heat dissipation and

**TABLE 2. The effect of ambient temperature  $T_a$  during thermal conditioning (TC), at 3 d of age on broiler chicken performance**

Treatment	Body weight <sup>1</sup> (g) (42 d)	Weight gain <sup>2</sup> (g/period) <sup>3</sup>	Feed intake <sup>2</sup> (g/period) <sup>3</sup>	Feed efficiency <sup>2</sup> (g/g)
<b>Trial 3 - <math>T_a = 36.0</math> C</b>				
Control	1,851 <sup>b</sup>	1,788 <sup>b</sup>	3,398	0.525
TC	2,040 <sup>a</sup>	1,977 <sup>a</sup>	3,575	0.552
SEM	37.17	36.14	88.90	0.011
<b>Trial 4 - <math>T_a = 37.5</math> C</b>				
Control	1,950 <sup>b</sup>	1,881 <sup>b</sup>	3,144	0.584
TC	2,070 <sup>a</sup>	2,005 <sup>a</sup>	3,300	0.607
SEM	31.46	31.65	55.02	0.0077
<b>Trial 5 - <math>T_a = 39.0</math> C</b>				
Control	2,081	2,015	3,580	0.562
TC	2,089	2,021	3,654	0.553
SEM	27.46	27.57	52.03	0.0065
<b>Trial 6 - <math>T_a = 40.5</math> C</b>				
Control	1,975	1,921	3,504	0.547
TC	1,982	1,924	3,455	0.557
SEM	63.69	64.07	88.41	0.0067

<sup>a,b</sup>Within columns, in each trial, values with different superscript letters differ significantly ( $P < 0.05$ ).

<sup>1</sup>n = 60.

<sup>2</sup>n = six replicates of 10 birds each.

<sup>3</sup>Period from 1 to 42 d of age.

**TABLE 3.** The effect of thermal conditioning (TC) of broiler chickens at the ages of 1 to 3 and 3 to 5 d on body temperature ( $T_b$ ) and triiodothyronine ( $T_3$ ) concentration before and after thermal challenge (TCh)<sup>1</sup>

Treatment	$T_b$ - prior to TCh (C)	$T_b$ - post TCh (C)	$T_3$ - prior to TCh (pg/mL)	$T_3$ - post TCh (pg/mL)
Trial 1				
Control	41.98 <sup>b</sup>	44.08 <sup>a</sup>	1,445 <sup>a</sup>	477 <sup>b</sup>
TC - Day 1	41.81 <sup>b</sup>	44.20 <sup>a</sup>	1,518 <sup>a</sup>	343 <sup>b</sup>
TC - Day 2	41.88 <sup>b</sup>	43.38 <sup>a</sup>	1,449 <sup>a</sup>	360 <sup>b</sup>
TC - Day 3	41.78 <sup>b</sup>	43.85 <sup>a</sup>	1,381 <sup>a</sup>	390 <sup>b</sup>
SEM	0.11	0.49	203	64.9
Trial 2				
Control	41.85 <sup>b</sup>	44.48 <sup>a</sup>	1,714 <sup>a</sup>	918 <sup>b*</sup>
TC - Day 3	41.63 <sup>b</sup>	43.22 <sup>a</sup>	1,475 <sup>a</sup>	378 <sup>b***</sup>
TC - Day 4	41.43 <sup>b</sup>	44.35 <sup>a</sup>	1,775 <sup>a</sup>	646 <sup>b**</sup>
TC - Day 5	41.52 <sup>b</sup>	43.83 <sup>a</sup>	1,822 <sup>a</sup>	482 <sup>b***</sup>
SEM	0.071	0.37	143	88.1

<sup>1</sup>Within rows and columns, values with different superscript letters (<sup>a,b</sup>) or asterisks (\*, \*\*, \*\*\*), respectively, differ significantly ( $P < 0.05$ );  $n = 10$ .

heat production (Horowitz, 1998). Acclimation is a more extensive adaptation than thermal conditioning, which involves hypothalamic thermoregulatory threshold changes that enable chickens, within certain limits, to cope with acute exposure to unexpected hot spells (Yahav, 2000). Acclimation improves thermotolerance, but it negatively impacts birds' production capacities. Therefore, thermal conditioning may be a useful tool for the simultaneous improvement of both thermotolerance and performance. The disadvantage of thermal conditioning lies in its inability to raise thermal tolerance close to the level achieved through acclimation.

Thermal conditioning resulted in growth retardation followed by an immediate compensatory growth period, which resulted in complete compensation for the loss of weight gain, and led to higher body weight of the conditioned chickens at 42 d of age. The extent of growth retardation and the subsequent compensatory growth that followed may be affected by the day of application of thermal conditioning and by  $T_a$ . Previous results (Yahav and Hurwitz, 1996; Yahav, unpublished data), dem-

onstrated that, as the period of thermal conditioning was extended, the compensatory growth response deteriorated; therefore, 24 h was selected for the present study. In this study thermal conditioning elicited similar effects on body weight when it was applied at the ages of 2 and 3 d or 3 and 5 d (Trials 1 and 2, respectively). However, because the best feed efficiency was observed in those chickens treated on Day 3, it can be recommended that this procedure may achieve the best performance.

The optimal  $T_a$  to be used for thermal conditioning was indicated to be 36.0 or 37.5 C. Exposure to these conditions resulted in significantly higher body weights at marketing age (189 and 120 g, respectively) than exposure to the other temperatures used. Furthermore, it was clearly demonstrated that when  $T_a$  was higher during thermal conditioning, the differences in body weight between control and treated chickens declined to 8 or 7 g, respectively, for exposure to 39 or 40.5 C. Although the best compensatory growth was demonstrated in chickens treated at 36.0 C, those that were thermally conditioned at 37.5 C had the lowest mortality rate (12.2%) during thermal chal-

**TABLE 4.** The effects of ambient temperature ( $T_a$ ) during thermal conditioning (TC), at the age of 3 d, on body temperature ( $T_b$ ) and triiodothyronine ( $T_3$ ) concentrations of broiler chickens before and after thermal challenge (TCh)

Treatment	$T_b$ - prior to TCh (C)	$T_b$ - post TCh (C)	$T_3$ - prior to TCh (pg/mL)	$T_3$ - post TCh (pg/mL)
Trial 3 - $T_a = 36.0$ C				
Control	41.49 <sup>b</sup>	44.90 <sup>a</sup>	1,325 <sup>a</sup>	936 <sup>a</sup>
TC	41.29 <sup>b</sup>	44.76 <sup>a</sup>	1,113 <sup>a</sup>	840 <sup>b</sup>
SEM	0.15	0.28	110	89
Trial 4 - $T_a = 37.5$ C				
Control	41.03 <sup>b</sup>	45.25 <sup>a</sup>	2,057 <sup>a</sup>	875 <sup>b</sup>
TC	40.99 <sup>b</sup>	45.19 <sup>a</sup>	1,853 <sup>a</sup>	635 <sup>b</sup>
SEM	0.18	0.27	115	73
Trial 5 - $T_a = 39.0$ C				
Control	41.64 <sup>b</sup>	45.22 <sup>a</sup>	1,998 <sup>a</sup>	1,426 <sup>b</sup>
TC	40.88 <sup>b</sup>	44.94 <sup>a</sup>	1,980 <sup>a</sup>	1,189 <sup>b</sup>
SEM	0.13	0.20	43	143
Trial 6 - $T_a = 40.5$ C				
Control	41.05 <sup>b</sup>	45.60 <sup>a</sup>	1,503 <sup>a</sup>	865 <sup>b</sup>
TC	40.84 <sup>b</sup>	45.27 <sup>a</sup>	1,355 <sup>a</sup>	990 <sup>b</sup>
SEM	0.16	0.25	91	73

<sup>a,b</sup>Within rows, values with different superscript letters differ significantly ( $P < 0.05$ );  $n = 10$ .

lenge and were able to modulate plasma  $T_3$  concentration to the lowest level, i.e., they were the most able to reduce heat production under extreme conditions of thermal challenge. However, they exhibited higher  $T_b$  at the end of the challenge, which may have resulted from insufficient heat dissipation.

The results of this study suggest that thermal conditioning at the age of 3 d and  $T_a$  between 36.0 and 37.5 °C produced optimal conditions for improving performance and thermotolerance in broiler chickens. However, from the practical viewpoint, the optimal temperature for thermal conditioning may vary according to economic factors such as feed cost and meat price.

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